Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SCG67-01 Room:201A Time:May 25 09:00-09:15

Reevaluation of horizontal crustal strain in the Tohoku District: a possible scale error in the baseline survey

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One of the causes of underestimating seismic potential of the 2011 Tohoku-oki earthquake (M9.0) was that E-W contraction in the Tohoku district was not clear in the strain distribution for 100 years. For the calculation of strain distribution, the triangulation survey results in the Meiji era was used as the reference coordinates. However, in the triangulation survey, only direction measurements among benchmarks are conducted, and the result may contain significant scale errors. The scale of the triangulation network is defined by baseline surveys. 15 baselines of 3-10 km length were directly measured using a steel baseline rod before the direction measurement. In the Tohoku district, they measured two baselines, the Shionohara baseline in Yamagata prefecture, and the Tsurunokotai baseline in Aomori prefecture. The original record of Shionohara baseline (5172m) exists in the archive of the Geospatial Information Authority of Japan. The maximum difference among 4 repeated measurements is only 14mm, implying a scale error of at most 2ppm. On the other hand, I found that the baseline was measured in May-June of 1894. On October 22, 1894, the Shonai earthquake (M7.0) occurred about 30km to the west of the baseline. A fault model calculation implies that the baseline might be elongated more than 50mm due to the coseismic deformation. In such a case, the scale of the triangulation network for the whole Tohoku district may be underestimated by about 10ppm, which could conceal the tectonic signal of E-W contraction in the strain distribution during 100 years.

Keywords: horizontal crustal strain, triangulation, baseline survey, scale error, Shonai earthquake, Tohoku-oki earthquake

SCG67-02 Room:201A Time:May 25 09:15-09:30

Systematic Errors in the Inversion Analysis of GPS Data to Estimate Interseismic Slip-deficit Rates at Plate Interfaces

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Through GPS measurements we can determine the current coordinates of observation points in a geodetic reference frame. To estimate interseismic slip-deficits at plate interfaces, we usually analyze GPS displacement data, that is to say the difference between the current and previous coordinates of observation points. However, the GPS displacement data contain not only intrinsic deformation but also the rigid body translation and block rotation due to intraplate inelastic deformation, which cannot be explained by interplate slip-deficit models based on elastic dislocation theory. In the inversion analysis of interseismic GPS data, unlike coseismic GPS data, we cannot ignore the theoretically unexplainable coherent noise (systematic errors), because they will seriously bias the inversion results. If the intraplate inelastic deformation is caused by fault slip at well-defined block boundaries as in the case of southwest Japan, we can apply the method of simultaneous GPS velocity data inversion for block rotations and block-boundary slip rates, proposed by McCaffrey (2002). In the case of central Japan, however, the cause of intraplate inelastic deformation is the brittle fracture and/or plastic flow at a number of defects spreading over indefinite tectonic zones (Sagiya et al. 2000, Noda & Matsu'ura 2010). So, we cannot apply the method of simultaneous GPS velocity data inversion. Another and more effective way to remove the rigid body translation and block rotation from GPS array data is to transform observed horizontal displacement vectors into average strain tensors for individual triangles composed of adjacent GPS stations. Applying an inversion formula based on Bayesian statistical inference theory (Matsu'ura et al., 2007) to the GPS strain data, we can obtain unbiased slip-deficit rate distribution. In this talk, we show the theoretical basis for the use of the average strains instead of horizontal displacement data, and demonstrate the applicability of the method of GPS strain data inversion through the analysis of interseismic GPS velocity data (1996-2000) in the Japan region (Hashimoto et al. 2009, Hashimoto et al. 2012, Noda et al. 2012), where the North American, Pacific, Philippine Sea, and Eurasian plates are interacting with each other in a complicated way.

Keywords: Systematic errors, Inverse problem, GPS data, Interseismic slip deficit

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SCG67-03 Room:201A Time:May 25 09:30-09:45

Non-planar Fault Source Modeling of the 2008 Iwate-Miyagi Inland Earthquake (Mw6.9)

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Iwate-Miyagi Inland earthquake (Mw6.9) occurred on 14 June, 2008, in the northeastern Honshu, Japan. The epicenter is located along Ou mountain areas and the mechanism is reverse faulting. Geodetic observations such as GPS and SAR show the maximum of displacements greater than 2m, and their spatial distributions are quite complex. Especially, the Kurikoma2, one of the GEONET observation station, indicates localized large displacements that was difficult to reconcile with SAR-based observation data. Although fault models based either GPS or SAR have already been published (e.g., Ohta et al., 2008, Takada et al., 2009), no unifying models have yet to be proposed that can explain both GPS and SAR data We estimate a non-planar fault model that can explain both data. We reported the non-planar fault model based on GPS and SAR data in the meetings last year (JpGU, Seismological Society of Japan, The Geodetic Society of Japan). However, the model cannot explain the GPS data at Kurikoma2. As a result of trial and error, at last, we developed the fault model that can largely explain all data.

We first developed a non-planar fault model that explains the GPS data alone. The maximum dip slip is ˜5 m and that of strike slip is nearly 0.5 m. The slip components are localized under Kurikoma2. These slip distributions are consistent with a reverse fault motion and GCMT solution. The moment magnitude inferred from this model is ˜6.9. Thus, this model can well explain the displacements acquired by GPS, and it may suggest that east-dipping fault is unnecessary.

Using the geometry and the slip parameters, we performed an inversion analysis and confirmed whether or not the fault model could explain the SAR data. There are significant misfit residuals greater than 50 cm in radar LOS. Moreover, the calculated range-offset data reveal notable discontinuities in the misfit residuals. These results strongly suggest that the GPS-based co-seismic displacements do not capture what the SAR-based displacement data sets tell us. Besides the pixel-offset data around the epicenter, aftershock distribution data also support the existence of an east-dipping fault segment.

Adding the east-dipping segment, we finally developed the non-planar fault model that explains the GPS and SAR data. The differences from the model based on GPS data alone are slip distribution and its maximum magnitude. While the dip slip component distributed broadly in the west-dipping segment, it is rather localized in the southern part of the east-dipping segment, and few dip slips are derived in the northern part. The maximum dip-slip of east-dipping and west-dipping segment is ˜3.5m and ˜2.5m, respectively, and that of strike slip is ˜1.5m on both segments. These inferred slip distributions are quite consistent with the lack of east-dipping lineament in the aftershock distribution. The total moment magnitude including east and west-dipping segments is ˜6.9. Moreover, the location of top edge on the east-dipping fault matches to the steep gradient of Bouger gravity anomaly.

SCG67-04 Room:201A Time:May 25 09:45-10:00

Frictional properties of the Bungo Channel slow slip region deduced from geodetic data

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Although slow slip events are detected in many of subducting plate convergence zones, they have various slip, slip rates, magnitudes, periods of duration and occurrence intervals and it is considered that they are controlled by frictional properties on sliding surface. There were some researches that estimated the relationships between slip and stress change or slip rate and stress change by spatiotemporal slip distribution of slow slip until now, but that analyses of them lacked credibility themselves and they had problems with the interpretations as frictional properties because they analyzed only one event. Therefore, we analyzed slow slip events that occur with a period of about six years in Bungo Channel by use of the identical estimation method and intended to estimate frictional properties in slow slip occurring area by affirming the reproducibility of the results. Three slow slip events in 1996˜1998, 2003˜2004 and 2010 were detected in Bungo Channel, and we analyzed all of these events. We used the daily positions of F3 components of GEONET that were eliminated secular velocities and seasonal changes estimated from the period with no large seismicity (2007˜2008) as the data. We estimated spatiotemporal slip distributions of each event by the time-dependent inversion method (Segall and Matthews, 1997). Based on estimated results, we calculated stress change on the plate interface by using the elastic dislocation theory (Okada, 1992). We considered that the relations of slip and stress change, slip rate and stress change represented frictional properties and compared those results each other. In the result, we obtained similar spatial distributions of eventual slip with the maximum slip of 20cm in 40km-depth although the slip, slip rates and periods of duration were different in each event. In the first event we found the center of slip migrated from 25km-depth to deeper area, but this slip migration was not seen in the other events. The area with large stress drop corresponded to that with large slip and maximum stress drop were 0.1-0.12MPa. The areas that had little stress change or increase of stress were extended around stress drop area. The plots of slip and stress change of three events were almost in a linear manner in common, and they did not vary with time, therefore this indicates that the estimated results represented the properties of the field. The relationships between slip and stress change were negative gradient in the area of large slip and it means that the area has a property of weakening. On the other hand, the area with zero or positive slope, that is, the area in which stress change was nearly zero or decreased extended around the negative-gradient-area. That area with a property of strengthening inhibits the expansion of slip, so it is suggested that slow slip events occur in episodic manner in Bungo Channel area because of such a spatial variation of frictional properties.

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SCG67-05 Room:201A Time:May 25 10:00-10:15

The 2011 Megathrust Earthquake off Northeast Japan and Multiple Earthquake Cycles in Subduction Zones

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The occurrence of earthquakes is the sudden release of tectonically accumulated stress by faulting. In the case of interplate earthquakes, the stress accumulation is caused by the interseismic gradual increase of slip deficits in source regions, and so the occurrence of earthquakes can be also regarded as the sudden recovery of the slip deficits. Since the crustal deformation due to the interseismic slip-deficit increase is detectable by GPS array observations as well as that due to the coseismic slip-deficit recovery, we can now monitor the slip-deficit and -recovery processes at plate interfaces through the inversion analysis of GPS array data. On March 11th of 2011, the Mw9.0 mega-thrust earthquake occurred at the North American and Pacific plate interface off Tohoku, Japan. The inversion analysis of GPS data for an interseismic period (1996-2000) before this earthquake has shown the five remarkable slip-deficit zones distributed on the plate interface along the southern Kuril-Japan trench. On the other hand, from the inversion analysis of coseismic GPS data, we revealed that the fault slip of the 2011 mega-thrust earthquake has a bimodal distribution with the northern main peak of 25 m and the southern sub peak of 6 m, which correspond to the Miyagi-oki and Fukushima-oki slip-deficit zones, respectively. In the Miyagi-oki slip-deficit zone, ordinarily large (M7.5) earthquakes with about 3 m coseismic slip have repeated every 40 years in the past two centuries. The occurrence of extraordinarily large earthquake with 25 m coseismic slip in the same slip-deficit zone suggests a possibility of scale-dependent multiple earthquake generation cycles, and leads to the conclusion that the so-called asperity is not a physical substance but a concept representing the spatial irregularity in frictional properties of faults.

Keywords: subduction zone, megathrust earthquake, stress accumulation, slip deficit, multiple earthquake cycle, scale dependence

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SCG67-06 Room:201A Time:May 25 10:15-10:30

Absolute stress release in the 2011 Tohoku-oki earthquake and pseudo-cyclic behavior of gigantic interplate earthquakes

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The rupture process of the 2011 Tohoku-oki earthquake is characterized by a large maximum slip (50 m), long slip duration (90 s), and a large stress drop (20 MPa). The long slip duration, large stress drop, extensional (normal faulting) aftershocks in a previously compressional stress regime, and low-angle normal slips at approximately the depth of the plate interface suggest that the earthquake released roughly all of the accumulated stress on the plate interface. In order to release roughly all of the accumulated stress, significant weakening of frictional strength on the fault plane must occur due to some mechanisms, such as thermal pressurization of pore fluid on the fault plane. Such dynamic weakening mechanisms of frictional strength are considered to be highly non-linear, and so strongly depends on the parameter conditions just before the earthquake. Then, the periodic occurrence of large interplate earthquakes (megaquake super-cycle) may be questioned. In fact, the most well-known sequence of large interplate earthquakes along the Nankai trough, Japan, shows repeated occurrence of them, but the periodicity is not good; the minimum interval is 90 years and the maximum 264 years [Ando, 1975]. Large variance of the recurrence interval (100 - 800 years) of outsized tsunami deposits along the Pacific coast of Hokkaido, Japan [Sawai, 2009] is also reported. Such pseudo-cyclic behavior of large interplate earthquakes can be understood by constant accumulation of stress due to steady plate motion and accidental release of stress due to dynamic weakening that strongly depends on initial conditions. If so, prediction of M9 events may be fundamentally difficult.

Keywords: 2011 Tohoku-oki earthquake, rupture process, absolute stress, megaquake, super-cycle

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SCG67-07 Room:201A Time:May 25 10:45-11:00

The October 23, 2011 Van-Ercis Earthquake (Eastern Turkey, Mw=7.2) and Characteristics of its Aftershocks

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The intraplate Van-Ercis earthquake took place about 100 km to the north of a suture zone undergoing N-S shortening resulting from the ongoing convergence of Arabian and Eurasian plates. The earthquake caused significant damage and loss of life in the cities of Ercis located on the hanging wall, 20 km to the north of the rupture zone, and Van, lying on the foot wall. No significant surface rupture was observed associated with the earthquake except some discontinuous displacements along a 20-25 km long trace extending N250E, between the Lakes Van and Ercek, where the northern block is uplifted a few centimeters.

Despite the large magnitude and the complex source region the teleseismic body waves are rather simple. The aftershock distributions and the finite source modeling depict a 60 km long rupture zone with average strike, dip and rake of 248, 36 and 56 degrees, respectively. The location of the epicenter and the extent of the aftershock area suggest that the rupture propagated bilaterally for about 30 km eastward and westward, mostly confined between the depth range of 20 km and just below the surface. The western part of the finite fault model zone show predominantly pure thrusting while the rest shows oblique reverse faulting that is approved by the mechanisms of the major aftershocks.

We retrieved 350 moment tensors for the aftershocks in the magnitude range $3.5<Mw<5.9$. We investigate the source characteristics of the aftershocks and their kinematic and dynamic relation with the mainshock. The spatial distribution of the aftershocks and their focal mechanism portrays distinct features. In total, about 45% of the CMT solutions of the aftershocks show predominantly reverse faulting or transpression; 40% of them show predominantly strike-slip faulting; and, 15% show normal faulting or transtension. The aftershocks in the NE corner of the rupture zone experienced mostly strike slip faulting pointing out conjugate strike-slip fault system at the lower crust reaching 30-35 km depth range. We determined tens of aftershocks showing normal faulting mechanism or transtension. Most of them are to the west and to the south of the epicenter. The southern aftershocks reflect transtension within the foot wall. The largest aftershock in the transtensional region took place on November 9, 2011 with magnitude Mw=5.7 just a few km away from the city Van. It generated rather complex waveforms which we modeled with two subevents one of them showing normal faulting.

Keywords: Arabia-Eurasia Convergence, Eastern Turkey, 2011 Van earthquake, mainshock, aftershocks

SCG67-08 Room:201A Time:May 25 11:00-11:15

Three dimensional deformation of accretionary wedge: insights from wide sandbox experiments

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Wide sandbox experiments are used to study the three dimensional deformation processes of accretionary wedge. In previous studies, they mainly focus on two dimensional deformation in depth and subduction directions or introduce intentional heterogeneity in the incoming plate such as seamounts. Although we do not introduce any intentional heterogeneity, the results show that wedge front shape is spontaneously curved as seen in the real subduction zones.

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SCG67-09 Room:201A Time:May 25 11:15-11:30

The crustal viscosity gradient measured from post-seismic deformation: a case study of the 1997 Manyi (Tibet) earthquake

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It is by now widely accepted that viscosity in the lithosphere has a significant variation with depth because of its temperature dependence, which should be involved for studying viscous relaxation in a geodetically observed post-seismic deformation. Using 3-D finite element model, we previously described the surface displacement history of a linear Maxwell visco-elastic model with depth-dependent viscosity (DDV) following a strike-slip fault event, in comparison of a uniform viscosity (UNV) model behaviour, showing that an apparent UNV (Eta_u) that best-fits the DDV model displacement at each surface point decreases with distance from fault, and the rate of the change of Eta_u with distance from fault reflects the vertical gradient of the viscosity. In the present study, we analyse an InSAR dataset of the surface deformation in a three year period following the 1997 Manyi (Tibet) earthquake [Ryder et al., GJI, 169, 1009 - 10027, 2007] in order to estimate the vertical viscosity gradient beneath the region. We first adopt UNV model to the surface displacements observed after an initial period ($t > 165$ days) in which post-seismic slip is probably significant, which reveals a clear signature of the vertical viscosity gradient in the crust: Eta_u with which the UNV model prediction best-fits the observed displacement decreases with distance from fault. The rate of the change in Eta_u with distance from fault then derives a crustal DDV structure which indicates that the 1997 Manyi event occurs within an upper layer that effectively deforms in elastic on the time-scale of the inter-seismic period, ~ 420 - 850 yrs [van der Woerd et al., GRL, 27, 2353-2356, 2000] and whose vertical gradient is consistent with the empirically derived steady-state power law creep of the upper crustal materials. The viscosity structure of the Tibetan crust constrained in this study advances the knowledge of the crust and assist in better understanding of the stress redistribution during the earthquake cycle.

Keywords: Post-seismic deformation, Viscous relaxation, Linear Maxwell visco-elasticity, Depth-dependent viscosity, Effective elastic thickness

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SCG67-10 Room:201A Time:May 25 11:30-11:45

Paleo shoreline profiles of lake Nam Co and the rheology of the Tibetan mid crust

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A major point of dispute in the tectonics of the Tibetan Plateau is whether the mid crust is weak enough to flow decoupled from the upper crust. Flow of the mid crust over distances of 100s or 1000s kilometers has been proposed and inflow of relatively low viscosity (no more than 10^{19} Pa s) rock from beneath the high plateau into the mid crust of the surrounding lower-lying regions has been proposed as a key process in the lateral growth of the plateau. However, different assumptions about the properties of the crust lead to the opposite conclusion: active deformation of the Plateau is better explained if the mid and upper crust of the plateau deform together and are not decoupled. Paleo lake shorelines offer a way to test these contrasting models and to contribute to our understanding of crustal rheology. Prominent shorelines developed around Lake Nam Co in central Tibet are excellent markers of the paleo horizontal in this region. Real time kinematic GPS surveys of these markers show there is no significant uplift despite a water level drop of several 10s meters. ^{14}C dating of lake tufa deposits shows the the age of a prominent shoreline at 20m above the present lake level to be between 10 and 20 ka. The lack of any isostatic response to water level drop over a time scale of more than 10,000 years implies either a high viscosity mid crust ($>10^{20}$Pa s) or a large elastic thickness to the crust. In either case these results imply that there is no continuous low viscosity mid crustal layer beneath Tibet in this area. We suggest that evidence for partially molten-and hence low viscosity-mid crust only reflects conditions of localized patches of crust. The lack of a continuous weak mid crustal layer argues against large-scale decoupling of the mid and upper crust. This implies that large-scale inflow of mid crustal rocks is unlikely to play a significant role in the expansion of the Tibetan plateau and that the mid crust can sustain significant stresses even on geological time scales.

Keywords: Tibet, Lakes, Mid crust, Rheology, Age

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SCG67-11 Room:201A Time:May 25 11:45-12:00

Uplift and denudation histories of mountainous areas of the Japanese Islands based on low-temperature thermochronology

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We used low-temperature thermochronology to provide quantitative constraints on the denudation and uplift history of some mountainous areas in the Japanese Islands. Quantitative analysis of uplift/denudation history requires estimate of uplift/denudation (rates) for a period of longer than 10^6 years, but only a few methods are available for its achieving. Over the last 40 years, thermochronometric methods have been successfully applied to major orogenic mountains, such as the Alps and Himalaya, to reveal their uplift/denudation histories. However, thermochronometric methods have hardly been able to make a significant contribution in revealing denudation history of mountains in young and low-relief orogens, such as the Japanese Islands because of precision and applicability of the methods. Over the past decade, the applicability of low-temperature thermochronology has extended considerably by practical use of (U-Th)/He thermochronometry, a rigorous understanding of annealing kinetics of the apatite fission-track system, and the improvement in inversion techniques for reconstructing thermal histories. In this study, currently available low-temperature thermochronometric methods, such as fission-track and (U-Th)/He methods, were comprehensively applied to the Rokko Mountains (Sueoka et al., 2010), Kiso Range (Sueoka et al., in press), and Akaishi Range (Sueoka et al., 2011) to reveal their uplift and denudation histories and to verify applicability of low-temperature thermochronometric methods to mountainous areas in a young orogen.

Keywords: low-temperature thermochronology, fission-track method, (U-Th)/He method, Rokko Mountains, Kiso Range, Akaishi Range